National Aeronautics and Space Administration
Goddard Space Flight Center
Contract No.NAS-5-12487

N69 15684

ST — LPS — RA — 10796

NASA CR-99136

RADIATION OF VENUS NEAR λ 1.35 CM

by

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(USSR)

14 JANUARY 1969

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Astronomicheskiy Vestnik
Tom 2, No.4, 217-228,
Izdatel'stvo "NAUKA", 1968.

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SUMMARY

The results are brought out of theoretical calculations of spectral characteristics of Venus' brightness temperature $T_{Я♀}$ in the λλ 0.75-165 cm band, and of investigations of planet's radioemission peculiarities due to the presence of H_2O in the atmosphere. The results of experimental measurements of $T_{Я♀}$ in the indicated interval of λ values agree well with the data on the parameters of Venus' atmosphere obtained on "VENERA-4". The "dip" in planet's brightness temperature by λ 1.35 cm appears to be either smaller or equivalent to the precision of $T_{♀Я}$ measurements, which, in most cases is ±10%. Presented here also are the spectral characteristics of Venus' brightness temperature in the wavelength interval λλ 0.3 -3.75 cm, determined by taking into account the results of measurments on "VENERA-4". (**)

* * *

During the past decade numerous measurements were performed on Venus' brightness temperature $T_{b♀}$ in a wide wavelength range λλ 0.1- 70 cm, which resulted in the idea on planet's emission spectrum in the superhigh frequency range. Radioastronomical investigations have shown, in particular, that in the 3 - 10 cm wave band, the value of T_{b}♀ is about 600°K, which is 2 - 3 times greater than could be expected, taking into account the planet's range from the Sun and its albedo. For the explanation of Venus' intense emission in the radioband, a hothouse hypothesis was introduced (see, for example, [1]). According to this hypothesis, the surface of the planet, which is heated

(*) IZLUCHENIYE VENERY VBLIZI λ 1.35 CM

(**) The Russian subscript Я stands everywhere for brightness. With the exception of formulas and tables, we shall use in the text the subscript "b" for brightness.

to high temperature from the action of the hothouse effect and its lower atmosphere, is responsible for the Venus' radioemission. At the same time it is presumed that the powerful hothouse mechanism is conditioned by the presence in the atmosphere of Venus of significant quantities of carbon dioxide and water vapor.

The Soviet automatic station "VENERA-4", accomplished a great complex of investigations directly in the planet's atmosphere [2-3]. Apparently, the surface temperature T_{surf} in the station's descent zone (on the planet's nighttime side near the line of morning terminator) is close to 550°K; the superficial pressure P_{surf} is of $\sim$ 20 atm, while carbon dioxide is the basic component of Venus' atmosphere. The contents of water vapor in the atmosphere was also found to be sufficiently high. Thus, the hothouse hypothesis fully agrees with the data obtained by "VENERA-4".

Among the radioastronomical investigations of Venus, a special interest is offered by the measurements of planet's brightness temperature in λ 1.35 cm and nearby wavelengths. The absorption line of molecule H_2O rotation spectrum, corresponds to the indicated wavelength. Therefore, it is possible to expect that the spectrum of Venus' brightness temperature has a "dip" in the vicinity of λ 1.35 cm due to the increase of atmosphere's absorption coefficient in this wavelength. According to the presence of "dip" and its depth, it is possible to judge about the contents of water vapor on Venus [4].

The first measurement of planet's brightness temperature in λ 1.35 cm was accomplished by Gibson and Corbett [5], who found that $T_{b♀}$ (1.35) = 520 ± 40°K, and drew a conclusion about the absence of the "dip" in the spectrum. Later, however, the same authors [6] gave for $T_{b♀}$ (1.35) another value in the period of lower conjunction: $\sim$ 435°K. During the flight of "MARINER-2" near Venus, measurements of brightness temperature of the planet side turned toward the spacecraft were performed from its board in $\lambda\lambda$ 1.35 and 1.9 cm [7]. The measured values of $T_{b♀}$ at the center of the visible disk in the indicated wavelengths, were found to be respectively 400 ± 100° and 590 ± 30°K. The obtained temperature drop permits, generally speaking, a conclusion about the noticeable absorption of radioemission by the H_2O vapors. However, during measurements by "MARINER-2", the radiometer "zero" in λ 1.35 cm was vigourously "floating" [7], so that this result cannot be considered reliable.

It is reported in the works [8-12] about the experiments, in which for the detection of the "dip", measurements of Venus' brightness temperature were conducted simultaneously in a series of wavelengths in the vicinity of λ 1.35 cm in the periods of time, corresponding to planet's different lower conjunctions. The results of these measurements are compiled in Table I.

TABLE I

RESULTS OF MEASUREMENTS OF VENUS' BRIGHTNESS TEMPERATURE NEAR λ 1.35 CM PERFORMED SIMULTANEOUSLY IN THE SERIES OF WAVELENGTHS

Welch and Thornton measurements [8,9]		Staelin and Barrett measurements [11, 12]		Staelin and Neal measurements [12]	
λ, cm	$T_{b♀}$, °K	λ, cm	$T_{b♀}$, °K	λ, cm	$T_{b♀}$, °K
0.835	390±45	0.93	430±42	1.18	400±36
0.97	412±55	1.02	463±68	1.28	418±38
1.16	495±50	1.18	428±46	1.35	436±39
1.24	451±53	1.28	450±41	1.43	451±41
1.35	530±45	1.37	404±39	1.58	477±57
1.46	595±50	1.42	502±100		
1.65	560±51				

It follows from Table I, that the Welch and Thornton [8,9] and Staelin and Neal's [12] measurement data differ from those of Staelin and Barrett [10,11]. According to [8,9,12], in λ 1.35 cm region there is not any peculiarity in the spectrum; but, according to [10,11] a "dip" is marked in the spectrum, whose depth is comparable, however, with the error in the measured values of $T_{b♀}$.

As regards the absolute values of brightness temperature, a better agreement is observed here between the results of Staelin and Barret [10,11] and Stael and Neal [12], while divergence between data of works [8,9], on the one hand, and [12], on the other, in λ 1.35 cm, exceeds the errors of measurements. Thus, the ground observations of various experiments have led to several contradictory conclusions about the character of radioemission of Venus near the resonance line of H_2O. However, it is possible to draw the conclusion, that the results of ground investigations are rather evidence of absence of the "dip" in the spectrum of Venus' brightness temperature in the vicinity of λ 1.35 cm.

The extent to which the results of radioastronomical investigations of Venus near λ 1.35 cm agree with the hothouse hypothesis and the data on structural parameters of venusian atmosphere, obtained by "VENERA-4" are examined below. At present time there is no sufficiently reliable information on the distribution of atmosphere's parameters over the surface. Therefore, while considering the planet's radioemission we shall assume that the structure of venusian atmosphere has a spherical symmetry. Then the brightness temperature of Venus in λ may be found by the formula

$$T_{я♀}(\lambda) = \frac{1}{\Omega_♀} \int\limits_{\Omega_♀} T_я(\lambda, r)\, d\Omega_♀ = \int\limits_0^{\pi/2} T_я(\lambda, r) \sin 2r dr, \tag{1}$$

where $\Omega_♀$ is the solid angle of the planet and $T_b(\lambda, r)$ is the brightness temperature distribution along the planet's visible disk, as a function of the central angle r.

A spherically symmetrical model atmosphere of Venus is considered in [13], which is based on the hothouse hypothesis, and a method is described for calculating the brightness temperature distribution about the planet's disk in the radioband, taking into account the roughness of its surface. In [13] the cloud cover of Venus is assumed to consist of water drops in its lower region, and ice crystals in the upper one. It is also assumed that the lower atmosphere is in a state of adiabatic equilibrium.

For the model of venusian atmosphere, considered in [13], computations of

T A B L E 2

BRIGHTNESS TEMPERATURE OF VENUS IN λ 1.35 CM AND DIFFERENCE $T_{b♀}$ (1.25)—$T_{b♀}$ (1.35) (P_{surf} = 20 atm, f_{H_2O} = 0.007)

Wateriness $g \cdot m^{-3}$	$T_{b♀}$ (1.35), °K				Wateriness $g \cdot m^{-3}$	$T_{b♀}$ (1.25) − $T_{b♀}$ (1.35)			
	T_{surf} = = 550°K	T_{surf} = = 600°K	T_{surf} = = 650°K	T_{surf} = = 700°K		T_{surf} = = 550°K	T_{surf} = = 600 K	T_{surf} = = 650°K	T_{surf} = = 700°K
0.2	403	430	452	466	0.2	−3	5	20	68
0.4	395	421	441	454	0.4	−4	3	17	42
0.6	388	412	431	444	0.6	−5	1	14	36
0.8	381	404	422	434	0.8	−5	0	11	32
1.0	375	396	413	425	1.0	−6	−1	9	28
1.5	361	380	394	404	1.5	−7	−4	5	20

spectral characteristics of planet's brightness temperature were performed in interval λλ 0.75 - 1.65 cm, with the aid of expression (1). Search for radioemission peculiarities of Venus due to the presence of H_2O in its atmosphere (see Table 2) was conducted in the indicated wavelength interval. The computations were performed for the following values of atmospheric parameters: P_{surf} = = 20 atm, T_{surf} = 550, 600, 650 and 700°K, f_{CO_2} = 0.95, f_{N_2} = 0.05 and f_{H_2O} = = 0.002 and 0.007, where f_{CO_2}, f_{N_2}, and f_{H_2O} are relative contents of CO_2, N_2 and H_2O in venusian atmosphere, equal to the ratio of partial pressures of indicated gases to the total value of pressure. The adiabatic temperature gradient in the undercloud layers of the atmosphere was assumed to be 8.9°K·km^{-1}. The presented values of atmospheric parameters correspond to data obtained by "VENERA-4" [2,3], as well as to the results of ground radioastronomical investigations of Venus [14]. It was assumed at computation, that the relative composition of the atmosphere does not vary with altitude, and that the dielectric constant of superficial formations is 1.5 [15], while the accounting for surface roughness was conducted exactly as in [13]. The thickness of the watery cloud layer was assumed of 2 km, its temperature being ~273°K, while wateriness $\underline{w}$ varied from 0.2 to 1.5 g·m^{-3}.

The absorption coefficient α^ν of Venus' atmosphere in the frequency ν, was determined as the sum of absorption coefficients in CO_2 and H_2O. In the centimeter and millimeter bands it may be written

$$\alpha^\nu = \alpha^\nu_{CO_2} + \alpha^\nu_{H_2O} = 2.1\cdot 10^{-7}\frac{P^2\nu^2}{c^2T^5} +$$
$$+ S\frac{N\nu^2\Delta\nu_2}{c^2T} + \frac{32\pi^2\nu_0{}^2\cdot N}{3ckTG(T)}|\mu_0|^2 \exp\left[-\frac{W(5,-1)}{kT}\right]\frac{\nu^2\Delta\nu_1}{(\nu^2-\nu_0{}^2)^2+4\nu^2\Delta\nu_1{}^2}. \qquad (2)$$

Here P is the pressure in dynes$\cdot$cm^{-2}; N is the number of molecules H_2O in 1 cm^3; S is a constant; $\Delta\nu_2$ is the parameter which takes into account the influence of spectral lines of H_2O, located in microwave band; c is the speed of light; G(T) is the rotational statistical sum; $\nu_0 = 2.2235\cdot 10^{10}$ hertz is the resonance line frequency in λ 1.35 (transition $5_{-1} - 6_{-5}$), while $\Delta\nu_1$, μ_0 and W (5, -1) are respectively the half width of the spectral line, the matrix element of the dipole moment and the lowest energy level for this transition.

The first addend in (2) takes into account the contribution of CO_2 to the absorption [16], the second addend takes into account the contribution of H_2O spectral lines' low frequency "tails" of the microwave band [17], while the third describes the contribution to absorption, which is brought in by the resonance lines of water vapor in λ 1.35 cm [18,19]. When considering the radio-emission absorption in the cloud cover, it is necessary to add to the expression (2) the term, which takes into account the water drop influence [17].

The results of computations are plotted in Figs.1-4, together with the experimentally measured values of $T_{b♀}$ in the considered interval of λ values.

It follows, from the curves of Figs.1-4, that the presence of water vapor in the atmosphere of Venus could lead to the decrease of planet's brightness temperature in λ 1.35 cm, and in nearby wavelengths. However, the depth of the "dip" depends essentially on the values of spectral temperature and the wateriness of the clouds.

At T_{surf} = 550°K, the "dip" is practically absent. With the increase of

T_{surf} the planet's brightness temperature in λ 1.35 cm rises alongside with the depth of the "dip". On the other hand, with the increase of w the value of $T_{b♀}$ (1.35) and the "dip's" depth decrease. In order to characterize these effects numerically, the calculations performed with T_{surf} = 550, 600, 650 and 700°K, are compiled in Table 2 alongside with the values of $T_{b♀}$ (1.35) and the differences in $T_{b♀}$ in two nearby wavelengths: 1.25 and 1.35.

From the presented data it follows that even at maximum possible [2] H_2O content in Venus' atmosphere, it is hard to detect the "dip", since its magnitude is either less, or completely comparable with the precision of $T_{b♀}$ measurement which in most cases constitutes ± 10%.

Such character of Venus' radioemission dependence on T_{surf} and w is not difficult to explain. It is well known that $\Delta\nu \sim P$ [20]. Therefore it is easily seen from (2), that at $\nu = \nu_0$ the absorption coefficient of water vapor has an addend, whose magnitude is inversely proportional to the pressure. Inasmuch as this addend describes the contribution to the absorption of H_2O molecule's resonance line, the divergence between the atmosphere's optical depth τ_{atm} in λ 1.35 cm and in the neighboring wavelengths, and consequently, the difference in brightness temperatures and in the depth of the "dip" will decrease. But the decrease of T_{surf} corresponds to pressure increase in the cloud cover level, since at this point the cloud temperature does not vary. On the contrary, the rise of surface temperature leads to the increase of clouds' optical depth at $\nu = \nu_0$, and to its decrease in the neighboring frequencies. The decrease of the difference $T_{b♀}$ (1.25) – $T_{b♀}$ (1.35) as w increases, is explained analogously, since then the difference between the values of τ_{atm} in the indicated waves decreases.

Another peculiarity of computed characteristics of the Venus' brightness temperature is the relative independence of the "dip's" depth of the water vapor content in the atmosphere. The computed values of $T_{b♀}$ and of the differences $T_{b♀}$ (1.25) – $T_{b♀}$ (1.35) for f_{H_2O} = 0.002 and 0.007 at constant value of T_{surf}, are compiled in Table 3.

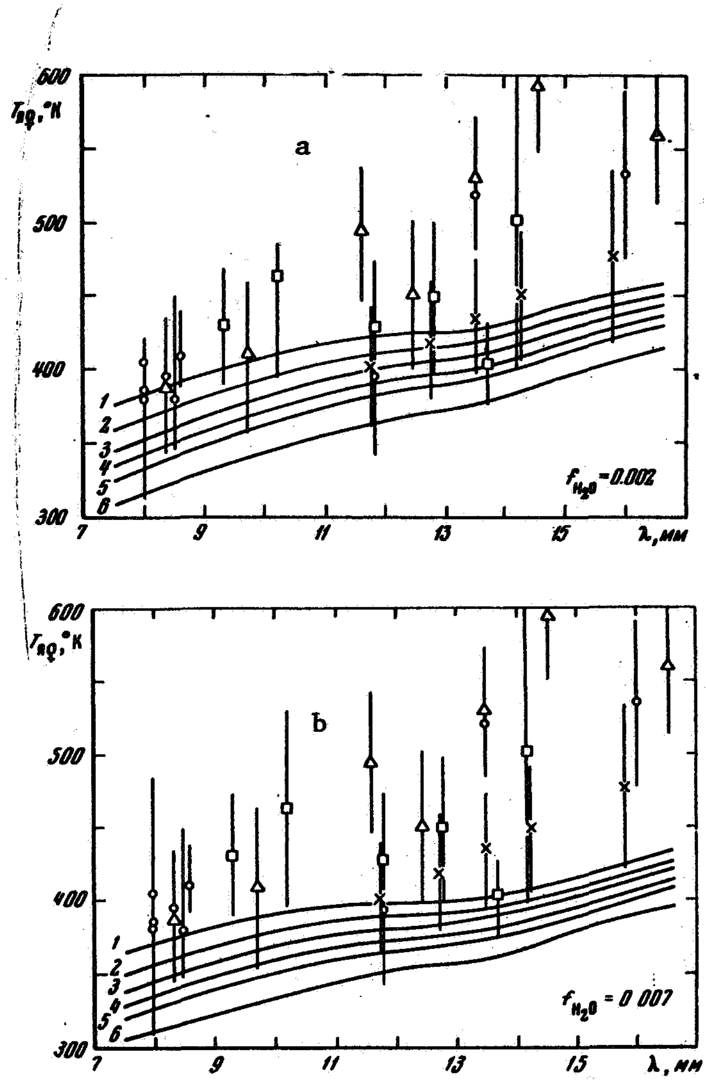
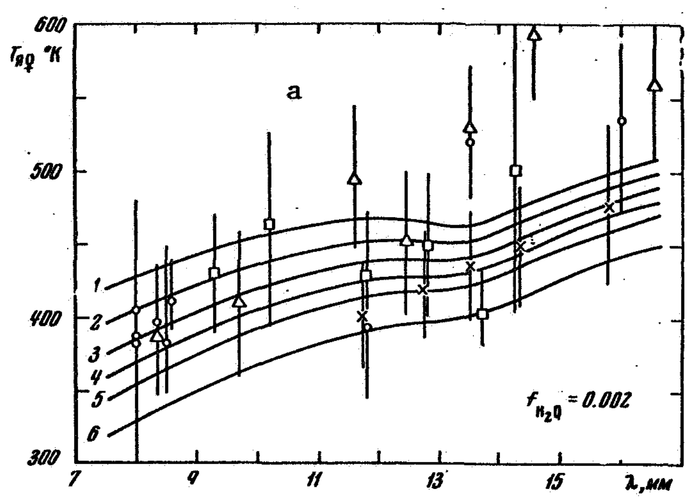


FIG.I a and b

Venus' emission near λ 1.35 cm (T_{surf} = 550°K);

a f_{H_2O} = 0.002; b f_{H_2O} = 0.007; 1 w = 0.2 $g \cdot m^{-3}$; 2 w = 0.4 $g \cdot m^{-3}$;
3 w = 0.6 $g \cdot m^{-3}$; 4 w = 0.8 $g \cdot m^{-3}$; 5 w 1.0 $g \cdot m^{-3}$; 6 w = 1.5 $g \cdot m^{-3}$.

Δ is the Welch and Thornton data [8,9], □ are the Staelin and Barrett data [10,11] are the Staelin and Neal data [12], 0 are other measurements.



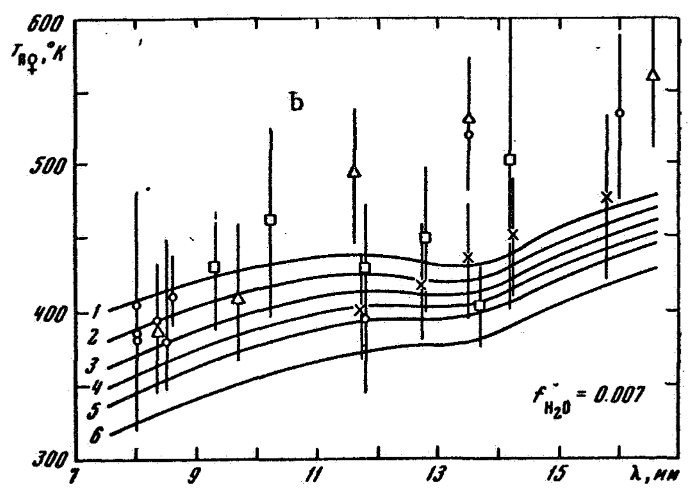


Fig.2 a and b

Venus' emission near λ 1.35 cm (T_{surf} = 6000°K):

a) f_{H_2O} = 0.002; b) f_{H_2O} = 0.007; 1 - 6) see Fig. I.

It follows from Table 3, that with the variation of f_{H_2O} value within the limits indicated by "VENERA-4" measurements (see [2]), the $T_{b♀}$ (1.25)-$T_{b♀}$ (1.35) difference remains practically constant. Thus, the f_{H_2O} value at constant surface temperature determines in the vicinity of λ 1.35 cm, mainly the absolute values of $T_{b♀}$ only.

As was noted above, the spectral characteristics, presented in Figs.1-4,

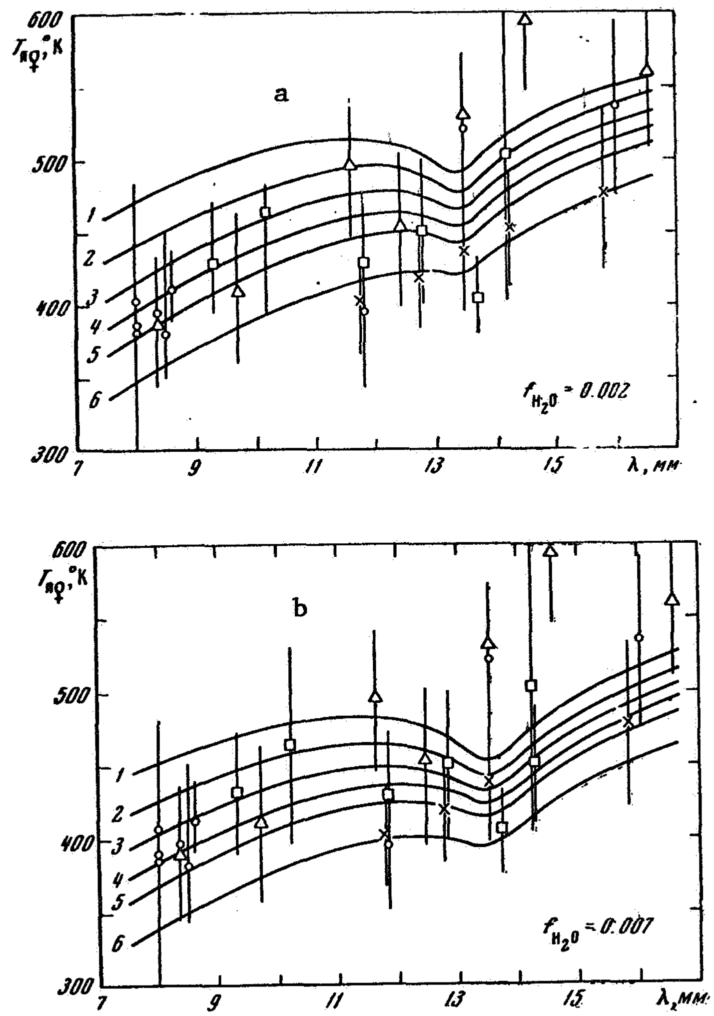


Fig.3 a and b

Venus' emission near λ 1.35 cm (T_{surf} = 650°K):

a) f_{H_2O} = 0.002; b) f_{H_2O} = 0.007; 1 - 6) (see Fig.1)

are found for an average temperature gradient in the undercloud atmosphere $\beta = 8.9°K \cdot km^{-1}$. The "VENERA-4" measurements have shown that the value of β varies with the altitude within small limits near the assumed average value [3], which is apparently connected with the dependence of carbon dioxide thermal capacity on temperature. In order to evaluate the dependence of the obtained results on the magnitude of temperature gradient, analogous computations of $T_{b♀}$ were performed for $\beta = 8$ and $10°K \cdot km^{-1}$. The computations show that

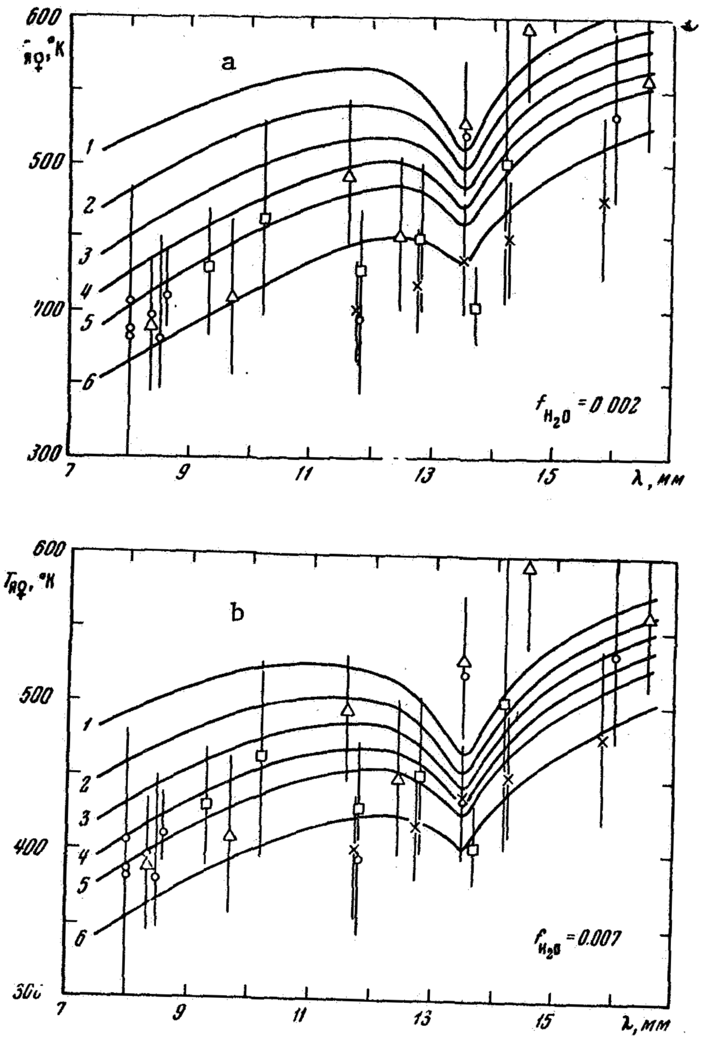


Fig.4 a and b

Venus' emission near λ 1.35 cm (T_{surf} = 700°K):

a) f_{H_2O} = 0.002; b) f_{H_2O} = 0.007; 1 - 6) (see Fig.1)

with the variation of temperature gradient by ±1°K·km^{-1} from the average value of β, the corresponding departures of theoretical values of $T_{b♀}$ from those presented in Figs.1-4 do not exceed ∿ 2% in the entire considered wavelength interval. Thus, the accounting of the real dependence of the value of β on the altitude will not result in any somewhat substantial variations in the results set forth above.

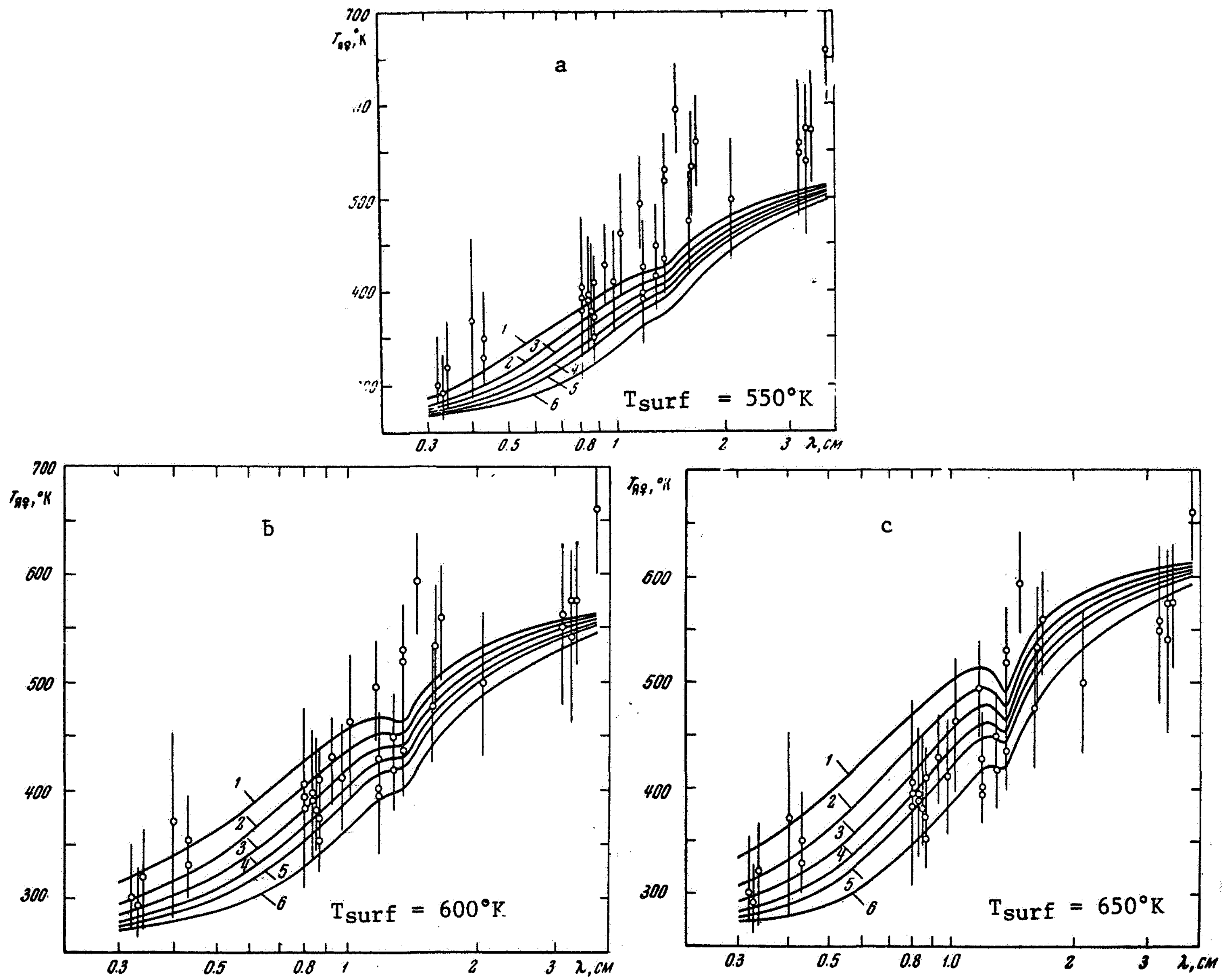
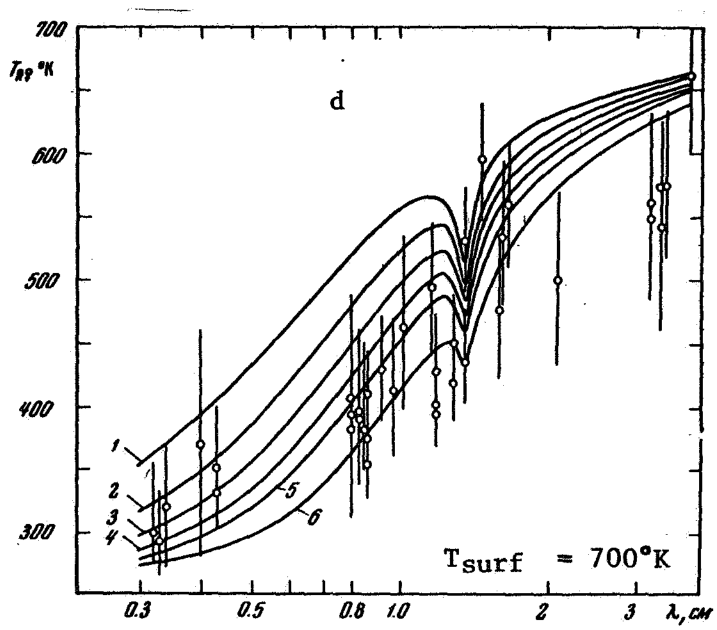


Fig.5 a, b, and c

Venus' emission in centimeter and millimeter waves:
a) T_{surf} = 550°K; f_{H_2O} = 0.002; b) T_{surf} = 600°K, f_{H_2O} = 0.002;
c) T_{surf} = 650°K, f_{H_2O} = 0.002; 1 - 6) (see Fig.1)



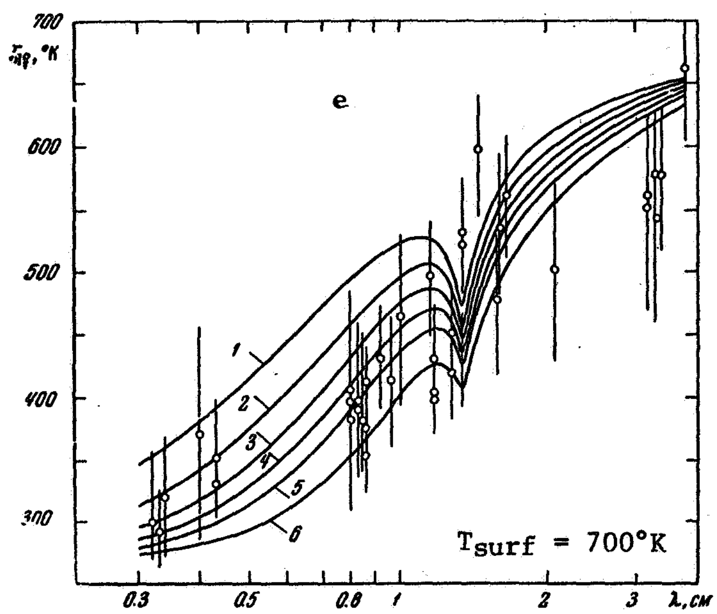


Fig. 5 d and e

Venus' emission in centimeter and millimeter waves:

d) $T_{surf} = 700°K$, $f_{H_2O} = 0.002$; e) $T_{surf} = 700°K$, $f_{H_2O} = 0.007$

1 - 6) (see Fig.1)

Let us turn now to the comparison of computed spectral characteristics with the experimental results of $T_{b♀}$ measurements in the λλ 0.75 - 1.65 cm interval. Here it is possible to note, first of all, that the model of Venus' atmosphere examined in [13] and based on the hothouse hypothesis, with parameters, corresponding to the data of "VENERA-4" measurements and the results of ground radioastronomical investigations of Venus, enables us to explain the general course of planet brightness temperature in the considered wavelength interval and also the insignificant depth of the "dip" in the value of $T_{b♀}$ at λ 1.35 cm. With the examined values of $T_{b♀}$ theoretical spectral characteristics of Venus' brightness temperature satisfy the results of measurements by Staelin and Neal [12], and Stalein and Barrett's [10,11]. Moreover with the variation of f_{H_2O} values, so do the values of w, for which the computed curves satisfy the experimental data.

The insignificant depth of the "dip" with P_{surf} = 20 atm, agrees also with the measurements of $T_{b♀}$ near λ 1.35 cm performed by Welch and Thornton [8,9]. However, as is seen from Figs.1-4, the curves plotted in the examined interval of T_{surf} values, do not satisfy the values of planet's brightness temperature measured in [8] in λ 1.35 and 1.46 cm, or in λλ 0.835 and 0.97. Apparently, the data of works [8,9] are satisfied for $T_{surf} > 700°K$ and $P_{surf} > 20$ atm.

Gibson and Corbett [6] reported about their discovered phase course of Venus brightness temperature in λ 1.35 cm. The $T_{b♀}$ (1.35) value rose with the increase of planet's illuminated part of the disk. The present computations demonstrate also that the brightness temperature of Venus in λ 1.35 cm should grow with surface temperature increase, regardless of noticeable H_2O content in the venusian atmosphere. According to Figs.1-4 the value of $T_{b♀}$ (1.35) for the assumed w values rises with the variation of T_{surf} from 550 to 700°K, by 40-60°K, if f_{H_2O} = 0.007 and by 55-85°K, if f_{H_2O} = 0.002.

It is shown in [21] that the model of Venus' atmosphere with watery cloud cover, based on hothouse hypothesis, allows the explanation of the experimental spectrum of planet's radioemission in centimeter and microwaves. The examination as to how could vary the results obtained in [21], taking account of the obtained by "VENERA-4" is of interest. The spectral characteristics of Venus' brightness temperature in the interval λλ 0.3 - 0.75 cm and found for the same conditions as the curves in Figs.1-4, are illustrated in Fig.5. Comparison of the obtained curves with the experimental results, which are also presented in Fig.5, shows that in a broader wavelength interval, the spectrum of Venus' radioemission agrees with the model of venusian atmosphere, based on the hothouse hypothesis and on the measurement data of "VENERA-4". Moreover, the cloud wateriness should be of same order as for the clouds of the Earth's atmosphere [22].

T A B L E 3

Brightness temperature of Venus in λ 1.35 cm and difference $T_{b♀}$ (1.25) — $T_{b♀}$ (1.35) (P_{surf} = 20 atm, T_{surf} = 650°K.

Wateriness $g \cdot cm^{-3}$	$T_{b♀}$, °K		$T_{b♀}$ (1.25) — $T_{b♀}$ (1.35), °K	
	f_{H_2O} = 0.0002	f_{H_2O} = 0.007	f_{H_2O} = 0.002	f_{H_2O} = 0.007
0.2	492	452	19	20
0.4	478	441	16	17
0.6	466	431	12	14
0.8	454	422	10	11
1.0	443	413	8	9
1.5	420	394	3	5

Thus, the hothouse hypothesis, taking into account the "VENERA-4" measurement data, and the radioastronomical investigations of Venus, allows us to explain the basic particuliarities of planet's radioemission in the vicinity of λ = 1.35 cm, and also in greater wavelength interval 0.3 - 3.75, where it is mainly determined by the venusian atmosphere. Computations show also that the $T_{b♀}$ depth of the "dip" in λ 1.35 should grow with the increase of surface temperature. Therefore there is interest in setting up experimental investigations of Venus' emission in the vicinity of λ 1.35 in the periods of planet's upper conjunctions.

The author extends his thanks to N.A. Armanda and M.A. Kolosova, for the attention paid to the work, and to A.G. Pavel'ev for the aid in its execution.

*** THE END ***

Institue of Radioengineering and Electronics AN SSSR

Manuscript received 14 May 1968.

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CONTRACT NO.NAS-5-12487

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Translated by
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on 6,8 and 9 Jan.1969
Revised by
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on 10 January 1969.